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The Trouble with Green Subsidies

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The Trouble with Green Subsidies

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Abstract

This paper explores the efficiency consequences of pursuing pollution reduction through a reliance on green subsidies rather than pollution taxes. It presents a stylized model of "subsidy-first" policy in which subsidies are rationalized by missing or incomplete taxes on some goods. It delineates five sources of inefficiency in subsidies, several of which relate to information requirements. In the model, green subsidies are justified because they induce substitution away from dirtier alternatives. Thus, subsidies hinge on counterfactuals, which creates information challenges analogous to the additionality problem. Insights from the model are used to comment on the Inflation Reduction Act.

Keywords: Green subsidies, Inflation Reduction Act, Pigouvian taxation
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1 Introduction

Perhaps the most fundamental prescription of environmental economics is that the most efficient path for addressing externalities is to directly price them, in the spirit of Pigou (1932). Some policies do directly price externalities through taxes or tradable permit schemes, but policy often does something quite different, like mandate technology adoption, cap ambient pollution levels, set performance standards, or subsidize green alternatives.

Subsidies for green alternatives are common, especially as they relate to energy and climate. In the US, green subsidies in the form of production and investment tax credits for renewable energy have arguably been the most important pillar of federal climate policy for three decades. With the passage of the Inflation Reduction Act (IRA) in 2022, green subsidies moved further to the core of climate policy. We now have generous subsidies covering key areas of transportation, power generation, residential buildings, commercial buildings, manufacturing, carbon capture and several key industrial processes.

Green subsidies differ from Pigouvian pricing instruments in the incentives they create, and thus in their economic efficiency. This article aims to provide a guide for economists and policy analysts to understand the efficiency properties of green subsidies. To do so, the article proposes a taxonomy of potential inefficiencies and explains their root cause and possible remedies.

The focus of this paper is on understanding what I call a "subsidy-first approach," which is when green subsidies are used *in lieu* of pollution pricing. I distinguish this approach from the Pigouvian approach that seeks to, as closely as possible, directly assign prices to emissions so that the social cost of pollution is internalized by market participants. In the Pigouvian approach, green subsidies can exist if they are rationalized by innovation and knowledge spillovers. The subsidy-first approach contrasts in that the subsidies are designed to address negative externalities that are left unaddressed in the absence of pollution pricing.

The paper develops a heuristic model in which a representative consumer chooses among four goods. Two are "green," and two are "dirty." For example, the two green goods might represent wind and solar power generation, while the two dirty goods might represent methane gas and coal generation. In the model, the Pigouvian approach applies a tax equal to the marginal externality to all goods. In a subsidy-first approach, it is assumed that the taxes on the dirty goods are missing, or incomplete, and second-best subsidies are derived in the context of these missing prices.

In the context of this simple model, the paper delineates five potential inefficiencies associated with a subsidy-first approach. The first issue is that the second-best subsidy scheme calls for differentiated subsidies across the two green goods, but calibration requires information about the substitution patterns across all goods and estimates of marginal damages of each good, whereas the Pigouvian approach requires only information about marginal damages. I argue that this information will rarely be available. As a result, differentiated subsidies will be inaccurate, or the policy-maker will resort to undifferentiated subsidies, which are less efficient. Resorting to uniform rates does not eliminate the need for information about substitution. I show that even uniform rates depend on substitution elasticities and thus require more information than analogous pollution pricing instruments.

For example, suppose the two green goods are plug-in hybrid vehicles (PHEVs) and fully electric vehicles (EVs), and the dirty goods are relatively efficient (low pollution) and relatively inefficient (high pollution) gasoline vehicles. If the gasoline vehicles are not (fully) taxed, the second-best tax on PHEVs and EVs could be a green subsidy, and the rates will depend on the substitution patterns across vehicles. The clean vehicles will get a larger subsidy if they create more substitution away from inefficient (high pollution) gasoline vehicles. PHEVs might have higher emissions than EVs but warrant a larger subsidy if they displace less efficient gasoline vehicles than do EVs. Lacking the relevant substitution information, policy might set the wrong relative subsidies or resort to a uniform subsidy.[1]

As another example, in theory a production tax credit for renewable power generation should vary based on the emissions of the power sources it displaces. The Environmental Protection Agency's Avoided Emissions and Generation Tool estimates that an increase in renewable power in New England reduces emissions by twice as much as the same power added in California.[2] The subsidy should therefore be twice as large in New England, but federal policy subsidizes energy production equally across space.

A second source of inefficiency is that subsidies will fail to adjust the relative prices of untaxed dirty goods. As an example, a subsidy-first approach does nothing to directly affect the relative price of coal versus methane gas in power generation. As a result, green subsidies fail to trigger low cost abatement that comes from switching among non-subsidizing actions. I refer to both of these issues as forms of "inevitable mispricing" in a subsidy-first approach. In a subsidy-first approach, there will be inevitable mispricing among green goods because subsidy differentiation requires information about substitution that is unlikely to be available, and there will be inevitable mispricing among dirty goods because subsidies cannot directly affect the prices of dirty goods.

A subsidy-first approach creates yet a third form of inevitable mispricing, this time across sectors. A pollution pricing system that spans transportation, power generation, industry, etc. can harmonize the marginal cost of abatement across sectors by setting a single price,

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[1] The model can readily be adapted to account for many products, so every vehicle type is a unique product. Allcott, Kane, Maydanchik, Shapiro, and Tintelnot (2024) show that different EVs create substantially different emissions reductions based on substitution patterns, which suggests that the ideal subsidy would differ across models. But, regulators lack this sort of information, especially before a policy is put into place. In practice, the EV tax credit varies based on domestic content requirements for batteries but does not attempt to scale the subsidy based on the emissions savings associated with different models.

[2] See https://www.epa.gov/avert/avert-web-edition.

provided that emissions can be observed and priced. Cost-effective abatement requires only information about emissions in a Pigouvian approach. In contrast, in a subsidy-first approach, harmonizing marginal costs across sectors requires differentiated green subsidies in each sector that hinge on substitution patterns as well as emissions rates. In the model, this issue can be understood by interpreting one clean and one dirty good as one sector of the economy and the other clean and dirty good as another sector. Setting efficient rates again requires information about substitution parameters.

A fourth inefficiency is associated with market size effects. The products or actions targeted by green subsidies are, with a few notable exceptions like carbon capture, things that themselves create pollution. They are subsidized because they create less pollution than the alternatives, not because they create negative pollution. Both the use and production of EVs, for example, involve carbon emissions, just less so (at least in most circumstances) than comparable petroleum vehicles. The Pigouvian solution would be to tax EVs and to tax petroleum vehicles even more, which will shift market share towards EVs and shrink the overall car market. Green subsidies can shift market share towards EVs, but they will make vehicles less expensive, causing an expansion of the market. This is the same scale effect that is created by performance standards or feebates. In some circumstances, this could be a significant efficiency cost, but in other cases I argue that this may turn out to be a feature rather than a bug.[3]

Fifth the revenue expenditures associated with green subsidies require other distortionary taxes to be raised, creating an efficiency cost through the marginal cost of public funds. Many green subsidies are targeted at a technology, product or action that is new and rare. In that case, the revenue costs may be small because the ratio of marginal actors incentivized by the program may be high relative to the number of inframarginal actors who collect revenue. As a green action or product matures, like wind and solar power generation, the revenue-related efficiency costs inevitably rise.

Table 1: A taxonomy of efficiency differences between Pigouvian and subsidy-first approaches

Category	**Description**
Green good mispricing	Information needs impede efficient differentiation of subsidies
Dirty good mispricing	Subsides cannot correct relative prices among dirty goods
Cross-sectoral mispricing	Information needs impede efficient relative prices across sectors
Market size effects	Subsidies make market too large
Revenue effects	Subsidies require revenue

Table 1 summarizes these five potential inefficiencies. This delineation may prove useful for

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[3] Note that even if the green goods created zero pollution, subsidizing them expands the market beyond the efficient benchmark.

researchers and policy analysts interested in understanding the potential pitfalls of relying on subsidies as a substitute for pollution pricing.

After using the model to discuss each of these five inefficiencies, the paper then relates them to the Inflation Reduction Act. Many of the provision of the IRA are designed to push market shares towards green alternatives in the absence of pollution pricing, which makes those provisions "subsidy-first" in spirit. The paper concludes by discussing the IRA in the context of the model and highlighting how the model might be used to understand potential inefficiencies and implementation challenges associated with the IRA.

The aim of this paper is to deepen understanding of potential inefficiencies from green subsidies. At the same time, there are reasons why green subsidies might be favored. Kotchen and Maggi (2024) demonstrate that green subsidies can have an efficiency advantage in an open economy model in noncooperative settings because subsidies to a cleaner alternative shift demand both home and abroad. This lies outside the model described in this paper, though the model could be readily adapted to incorporate multiple jurisdictions. More generally, green subsidies might hold additional efficiency advantages not explored in this paper in contexts where leakage across jurisdictions or sectors is substantial.

Other possible reasons to favor green subsidies relate to political economy. Green subsidies spread a revenue burden over a diffuse set of taxpayers and transfer those funds toward specific industries, which may give them an advantage in the traditional theory of collective action (Olson 1965). If the only way to achieve aggressive action given political constraints is a subsidy-first approach, then it may well be the best outcome. Indeed, Mann and Roberts (Forthcoming) trace the history of US energy policy to show how we arrived at the IRA. Even so, it is critical to have a clear understanding of its weaknesses both because it allows for a discussion of whether carbon pricing should be pursued if and when political opportunities arise and also because understanding the problems with green subsidies allows us to contemplate design changes or complementary policies that mitigate those weaknesses.

This paper is similar in spirit to Metcalf (2009b), which delineates a set of challenges associated with low-carbon subsidies and discusses scale effects and the problem of inframarginal recipients. My focus on information limitations and inevitable mispricing differs from Metcalf (2009b), though that article does include examples discussing when optimal subsidies should be differentiated in ways that prove impractical.

The points I make about revenue effects relate to a large literature on the double dividend hypothesis (e.g., Goulder 2009), and the concern about the challenge of reaching marginal consumers with green subsidies is discussed in Boomhower and Davis (2014) and DeShazo, Sheldon, and Carson (2017), the latter of which also models differentiated subsidies based on substitution. The issue of scale effects is well understood in the literature on performance standards (e.g., Holland, Hughes, and Knittel 2009). I argue that the points about mispricing due to misinformation emphasized in this paper are fundamentally the same problem as additionality, which has been well studied in the realm of offsets (e.g., Mason and Plantinga 2013; Wara 2008; Aspelund and Russo 2024). Similar in spirit to my argument, Salzman and Weisbach (2024) argues for an even broader view of additionality.

2 A simple framework for analyzing green subsidies

The model presented in this paper aims to be as simple as possible while capturing several key features. This paper is not about distributional issues, so the model assumes a representative, price-taking consumer. The consumer chooses levels of consumption of four goods, each of which has a per unit negative externality denoted $\phi_1 < \phi_2 < \phi_3 < \phi_4$, so that the goods are indexed in order by the level of the externality they create for convenience of interpretation.

The two goods with the lowest externality per unit are denoted as "green," and the quantities consumed (produced) of them are denoted G_1 and G_2. The quantities consumed of goods 3 and 4, which are labeled as "dirty," are denoted D_3 and D_4. The model allows that the externalities associated with a good could be positive (i.e., damages $\phi_1 < 0$), but in most cases the presumption is that all goods create a negative externality ($\phi_1 > 0$). In those cases, we may end up subsidizing the relatively clean goods in second-best situations because doing so induces switching away from even more harmful alternatives.

For ease of exposition, the consumer is assumed to have exogenous income Y that is spent on the four goods and a numeraire X.[4] I allow that the numeraire could have a negative externality, ϕ_X, though much of the analysis focuses on the case where $\phi_X = 0$. I write private utility as $U(G_1, G_2, D_3, D_4) + X$, whereas welfare also subtracts off the externality, which will be equal to $\phi_1 G_1 + \phi_2 G_2 + \phi_3 D_3 + \phi_4 D_4 + \phi_X X$.

The supply side is assumed to be competitive with constant returns to scale. Obviously, this means the paper will not comment on how green subsidies interact with market power. These assumptions mean that all tax burdens will be born by consumers. I denote producer prices as P_1 to P_4.

Policy is a set of taxes denoted s_1, s_2, t_3 and t_4. All four values are taxes if positive and subsidies if negative. The difference in notation aligns with the fact that most of our attention will be on cases where the second-best policy involves a subsidy for the green goods, which occurs if $s_1 < 0$ or $s_2 < 0$. Revenue from the tax (revenue needs for the subsidy) are recycled (funded) by a lump-sum demogrant Z.

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[4] Assuming that labor is exogenous abstracts from some issues related to the marginal cost of public funds and eliminates aspects of second-best policy tied to how each good is a substitute or complement for leisure, but it facilitates clarity on the main points around information by providing simple closed form solutions for second-best rates.

The consumer's problem is to maximize utility, taking prices, taxes, income and the demogrant as given:

$$\max_{G_1,G_2,D_3,D_4} W = U(G_1,G_2,D_3,D_4) + \underbrace{[Y+Z-(P_1+s_1)G_1-(P_2+s_2)G_2-(P_3+t_3)D_3-(P_4+t_4)D_4]}_{X}. \tag{1}$$

The social planner chooses the tax rates to maximize social welfare, which includes private welfare minus the externality, taking as given consumer behavior (which is to maximized equation 1) and the resource constraints in the economy (below, implicitly modeled as respecting the budget constraint of the consumer with implicit revenue recycling). The externality appears in both the term modifying the numeraire X if the numeraire has an externality (ϕ_X) as well as in the consumption of goods in the sector.

$$\begin{aligned}\max_{s_1,s_2,t_3,t_4} SWF = {} & U(G_1,G_2,D_3,D_4) \\ & + (1-\phi_X)\underbrace{[Y-P_1G_1-P_2G_2-P_3D_3-P_4D_4]}_{X} \\ & - \underbrace{[\phi_1G_1+\phi_2G_2+\phi_3D_3+\phi_4D_4]}_{\text{externality in sector}}. \end{aligned} \tag{2}$$

The discussion below offers a definition of a subsidy-first approach that can be modeled as a constraint on equation 2.

2.1 What is a subsidy-first approach?

This model allows us to offer a definition of a subsidy first approach and to compare it to a Pigouvian benchmark. This is shown in Table 2, which starts with the assumption that $\phi_X = 0$ for simplification (the alternative is discussed below).

Table 2: What is a subsidy-first approach?

Good	G_1	G_2	D_3	D_4	X
Externality per unit	$0 < \phi_1$	$< \phi_2$	$< \phi_3$	$< \phi_4$	0
Pigouvian benchmark	$t_1 = \phi_1$	$t_2 = \phi_2$	$t_3 = \phi_3$	$t_4 = \phi_4$	$t_X = 0$
Green subsidy	$\mathbf{s_1 = s_1^*}$	$\mathbf{s_2 = s_2^*}$	$t_3 = 0$	$t_4 = 0$	$t_X = 0$

In this case, the Pigouvian benchmark is simply to tax each of the four goods at a rate equal to their marginal damages. This is the standard result, which obtains without modification because we have assumed away any other market failures beyond the externality in the sector.

In contrast, I define a subsidy-first approach as a policy that imposes taxes (subsidies) per unit on the green goods only. That is, conditional on $t_3 = t_4 = t_X = 0$, the policy-maker chooses s_1 and s_2. Intuitively, because the externality per unit of the green goods is lower than the externality per unit of the dirty goods, the second-best tax on the green goods may be a subsidy. But, this will depend critically on substitution patterns, as shown next.

This same framework can accommodate situations where the dirty goods are taxed (explicitly or via a regulatory shadow price), but incompletely. To accommodate that case, we need only reinterpret ϕ_3 and ϕ_4 as the unpriced component of the externality. This opens the possibility that ϕ terms for the dirty goods could be smaller than the ϕ terms for the green goods. The derivations below do not require the rank ordering of the ϕ terms, so this possibility is accommodated in the formulas below.

The model does not explicitly consider learning spillovers. However, if there is a constant per unit positive spillover, then the ϕ terms can simply be interpreted as net externalities. In that case, s_1 or s_2 could be negative or positive. Nothing in the derivations below require that the ϕ terms be positive, so this interpretation can be accommodated by the formulas below.

2.2 Second-best green subsidies in a subsidy-first approach

The first result describes the second-best taxes in a subsidy-first approach, which means that the taxes on the dirty goods are set to zero.

Result 1. *When $t_1 = t_2 = t_X = \phi_X = 0$, the second-best subsidies are equal to:*

$$
\begin{aligned}
s_1^* &= \phi_1 - \phi_3 \left[\frac{\frac{\partial D_3/\partial s_2}{\partial G_2/\partial s_2} - \frac{\partial D_3/\partial s_1}{\partial G_2/\partial s_1}}{\frac{\partial G_1/\partial s_1}{\partial G_2/\partial s_1} - \frac{\partial G_1/\partial s_2}{\partial G_2/\partial s_2}} \right] - \phi_4 \left[\frac{\frac{\partial D_4/\partial s_2}{\partial G_2/\partial s_2} - \frac{\partial D_4/\partial s_1}{\partial G_2/\partial s_1}}{\frac{\partial G_1/\partial s_1}{\partial G_2/\partial s_1} - \frac{\partial G_1/\partial s_2}{\partial G_2/\partial s_2}} \right] \\
s_2^* &= \phi_2 - \phi_3 \left[\frac{\frac{\partial D_3/\partial s_1}{\partial G_1/\partial s_1} - \frac{\partial D_3/\partial s_2}{\partial G_1/\partial s_2}}{\frac{\partial G_2/\partial s_2}{\partial G_1/\partial s_2} - \frac{\partial G_2/\partial s_1}{\partial G_1/\partial s_1}} \right] - \phi_4 \left[\frac{\frac{\partial D_4/\partial s_1}{\partial G_1/\partial s_1} - \frac{\partial D_4/\partial s_2}{\partial G_1/\partial s_2}}{\frac{\partial G_2/\partial s_2}{\partial G_1/\partial s_2} - \frac{\partial G_2/\partial s_1}{\partial G_1/\partial s_1}} \right].
\end{aligned}
$$

The result follows from maximizing the social welfare function with respect to s_1^* and s_2^*, taking as given the consumer demand responses. (Derivation is in the appendix.) Recall again that, even though I am using the notation s, a positive value for s_1^* and s_2^* implies a tax. The second-best tax is a subsidy only if s_1^* and s_2^* are negative.

The results take an additive form. The first term is the externality of the green good itself—the larger is the externality the more likely it is that the green good has a positive tax in the second best. Alternatively, if the green good actually creates a positive externality, through direct pollution reduction or because ϕ is interpreted as capturing learning spillovers, then this component could justify a subsidy on its own.

The additional two terms relate to substitution towards the two dirty goods, respectively. Each of these terms multiplies the marginal damage of the dirty good times an expression relating several substitution terms. As long as the green goods are substitutes for each other and the dirty good, the entire bracketed terms will be positive. The larger this term, the larger will be the second-best subsidy. When the response of the dirty good quantity to the green good price is larger, the larger the subsidy will be. Intuitively, these substitution terms capture the benefit of lowering prices for the green good that come from reducing the demand for the dirty goods that have unpriced externalities.

To see the result more clearly, consider the case where $s_2 = \phi_2$ and the planner chooses only s_1. Then, the second-best tax, denoted $\tilde{s}_1$, is:

$$\tilde{s}_1 = \phi_1 - \phi_3 \frac{-\partial D_3/\partial s_1}{\partial G_1/\partial s_1} - \phi_4 \frac{-\partial D_4/\partial s_1}{\partial G_1/\partial s_1}.$$

This makes the intuition, that the second-best tax balances the green good's own externality with the degree to which price changes cause substitution to the other goods that are mispriced, easier to see.

The punchline is that the second-best tax on the green goods can well be a subsidy, but calibrating that subsidy requires information about substitution.[5] The reason we can get a subsidy is that subsidizing the green goods causes a movement away from (mispriced) dirtier alternatives. This is a particular form of a more general result that the corrective tax on a product can differ from marginal damages, even in sign, when a good is a complement or substitute for other goods that have unpriced (underpriced) externalities (Green and Sheshinski 1976; Davis and Sallee 2020; Tarduno 2022). The key point of this paper is that one needs to know both marginal damages and substitution patterns; in fact, the substitution patterns are the reason for a subsidy and are thus essential to the calibration.

2.3 Second-best uniform subsidies in a subsidy-first approach

In most circumstances, policy will not differentiate among green products, or will do so imperfectly. To capture that possibility, we can characterize the second-best uniform tax on the green products in a subsidy-first approach, where $s_u = s_1 = s_2$. Under the simplified assumptions above ($\phi_X = 0$, quasilinear numeraire, constant returns to scale perfect competition, price taking buyers and sellers), when $t_3 = t_4 = 0$, then:

Result 2. *When* $t_1 = t_2 = t_X = \phi_X = 0$, *the second-best uniform subsidy* ($s_u^* = s_1 = s_2$) *is*

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[5] In section 4 I briefly discuss the possibility of allowing $t_X \neq 0$. In that case, the Pigouvian approach also requires some information about substitution patterns, but less information than is required to set differentiated subsidies.

equal to:

$$s_u^* = \phi_1 \frac{\partial G_1/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u} + \phi_2 \frac{\partial G_2/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u}$$
$$- \phi_3 \frac{-\partial D_3/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u} - \phi_4 \frac{-\partial D_4/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u}.$$

The first two terms represent the Pigouvian component of the second-best uniform tax. They are a weighted average of the marginal damages, where the weights are the demand response. This is a manifestation of the standard result from Diamond (1973) about the second-best tax on a good with heterogeneous externalities.

The second two terms are the analogous substitution terms, where the ratios will be positive, so long as the dirty goods are substitutes for the green goods. When the green goods create negative externalities ($0 < \phi_1 < \phi_2$), a subsidy can arise only because of the substitution terms. Thus, as in the differentiated case above, the calibration of a uniform subsidy hinges entirely on knowing the rates of substitution across the green goods and the dirty goods. The uniform subsidy requires information about not just damages, but counterfactuals.

3 Potential efficiency costs associated with the subsidy-first approach

Each of the next five subsections discusses a specific way in which a subsidy-first approach might be less cost effective than a Pigouvian approach.

3.1 The inability to differentiate between green subsidies

As demonstrated in Result 1, the second-best differentiated subsidy rates are a function not just of marginal damages, but also of a matrix of substitution derivatives. This means that setting efficient green subsidies in a subsidy-first approach requires more information than is required to set taxes in the Pigouvian approach.

On one level, this can be understood as a manifestation of the familiar additionality problem. The additionality problem refers to situations where an agent claims that their behavior is the result of an intervention, but in fact they would have chosen the behavior regardless. In the context of environmental offsets, the additionality problem occurs when someone is paid for an action that they would have taken absent the payment.

At its core, the additionality problem in offsets stems from the need to reward behavior depending not just on observed actions, but also based on a counterfactual. The challenge of additionality is well known and often studied in the context of environmental offsets (e.g., Wara 2008; Mason and Plantinga 2013; Aspelund and Russo 2024). Offsets generally take some form of payment for an emissions reduction, and they can lead to adverse selection and baseline manipulation so that many payments go to non-marginal recipients. More generally, the inability to observe baseline behavior implies that offsets will create uneven incentives across abatement opportunities, which erodes efficiency. The view taken here is that the same problem exists in a broader set of green subsidies. Relatedly, Salzman and Weisbach (2024) argue for a broader view of additionality.

Green subsidies in a subsidy-first approach could differentiate across products in a way that reflects the second-best formulas described above in Result 1. In practice, they will often be far more coarse, and will more closely resemble uniform subsidies across all green goods, or across categories. This creates an inefficiency, and often this inefficiency is different than what would prevail in a Pigouvian approach.

Under a Pigouvian approach, a single price of emissions will typically create differentiated taxes at the product level. In contrast, under the subsidy-first approach, the differentiation cannot be achieved simply by assigning a dollar value to emissions rates because it is not the emissions differences across green products that drive the difference in subsidies, but rather the difference in their substitution patterns among dirty alternatives.

For example, the current version of the electric vehicle tax credit has a number of eligibility restrictions based on domestic production and price limits, but assuming the vehilce is eligible on those grounds, the subsidy is a flat $7,500 provided that the battery has at least a 7 killowatt hour capacity.

In fact, there is substantial heterogeneity in substitution patterns between different electric vehicle models and conventional alternatives (Xing, Leard, and Li 2021; Allcott et al. 2024), meaning that properly differentiated subsidies would likely vary a great deal. Recent second-choice data analyzed in Grieco, Murry, and Yurukoglu (2024) shows that the average plug-in hybrid is more likely to substitute for a vehicle with lower fuel economy than does a fully electric vehicle. This suggests that the second-best subsidy for plug-in hybrids may well be higher than for electric vehicles, despite their having higher emissions of their own. Without knowing substitution patterns among cars, which are difficult enough to learn ex post and are implausible to credibly estimate before a law is passed, there is no straightforward way to even try to differentiate green subsidies across vehicles.

Another example of this failure to differentiate is in the production and investment tax credits for renewable energy. These subsidies are constant no matter where in the country a generator is operating, even though estimates of the offset emissions are quite different. A policy that taxed emissions at fossil generators would create differentiated market opportunities for wind and solar depending on the grid in each location.[6]

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[6] Metcalf (2009a) makes the related point that in order to target subsidies at the marginal units, the subsidies should vary with capacity factors across space.

The relative importance of this issue can be gauged based on numbers provided by the Environmental Protection Agency's Avoided Emissions and Generation Tool (AVERT), which uses microdata on generation and emissions rates from power markets to estimate the emissions reductions that would follow from installing an additional generator in each part of the U.S. grid. That model shows meaningful variation in emissions across space. For example, an additional megawatt hour of renewable power in California is estimated to offset 0.4 tons of carbon dioxide emissions, whereas that number is 0.71 in the Midwest, suggesting that a PTC in the Midwest should be 75% higher than in California.

Similarly, federal tax credits for rooftop solar, energy efficiency improvements or the installation of heat pumps are uniform across location. The emissions implications can be quite different across location, however, because of differences in weather (which affects solar production as well as heat pump utilization) and differences in grid emissions.

Another dimension is time. As a market evolves, substitution patterns will change, and so the second-best subsidies should change as well, even if emissions rates of the green products and marginal damage estimates per unit of emissions are constant. For example, as the grid changes, the second-best subsidy for wind and solar should change, even if we have the same social cost of carbon. A Tesla Model 3 will displace a different set of vehicles from one year to the next based on the other products offered in the market, meaning that a second-best tax credit for the Model 3 would update ever year. This sort of constant updating is implausible in most circumstances, which creates another reason to expect inevitable mispricing among green products. In contrast, in the Pigouvian approach, the appropriate tax rate per unit of emissions needs to evolve only if the estimate of marginal damages changes.

One might argue that a uniform credit is logical if the motivation is to subsidize learning by doing or spillovers, where the key issue to produce additional units, not to target emissions that are offset. But, in a subsidy-first approach, failure to differentiate among products seems inevitable and inefficient. In most cases, this inefficiency is avoidable in the Pigouvian approach. And, even where a uniform subsidy might be approximately correct, as shown in Result 2, the calibration of that subsidy also depends directly on substitution parameters.

3.2 The inability to correct relative prices of brown choices

Another critical concern related to a subsidy-first approach is that by only targeting the "green products," the policy will fail to induce mitigation that comes from adjusting among the dirty goods. The inability to get the relative prices of green subsidies right is an information problem and, if differentiated subsidies are ruled out for practical reasons, an administrative or political challenge. In contrast, the inability to correct the relative prices of dirty products is inherent to a subsidy-first approach.

In power generation for example, most of the emissions reductions in recent years have come from natural gas (D_3) displacing coal (D_4) due in large part to the fracking revolution, which has ensured a more abundant supply of cheap natural gas. Policies that target renewables, as would occur in a subsidy first approach, fail to encourage these gains.[7] Closely related, renewables may have contributed to the substantial decline in nuclear power production, which also produces carbon free power. Under a Pigouvian approach, pricing the emissions of fossil generation would have given a relative advantage to nuclear. A reliance on subsidies for renewables fails to set relative prices of the non-subsidized alternatives.

As another example, consider electric vehicle tax credits that subsidize EVs (G_1) and plug-in hybrids (G_2) but do nothing to price the relative difference between conventional hybrids (D_3) and conventional vehicles (D_4). A subsidy-first approach simply cannot solve this problem unless a large fraction of the products qualify as "green" and thus get a subsidy. As the number of vehicles that are covered and are assigned a tax (subsidy) increases, the subsidy-first approach transforms into the Pigouvian benchmark, and the second-best subsidies will become taxes (assuming the green products have $\phi > 0$).

This gap in the mitigation incentives created by a subsidy-first approach is a key reason why a subsidy-first approach invites complementary policies. Such policies are highly relevant in both of the cases mentioned here. Air pollution and toxic regulations impact power plants and treat coal and natural gas differently, and fuel economy standards create additional relative pricing for cars. I return to this interaction in section 5.

3.3 The inability to harmonize prices across sectors

The last efficiency challenge under the umbrella of "inevitable mispricing" is the difficulty in harmonizing the relative subsidies across sectors. Efficiency requires harmonization of marginal costs of abatement across activities and sectors. In a Pigouvian approach, this is often feasible if the emissions or damages can be priced directly. Indeed, that is the entire appeal of the Pigouvian approach—if emissions (damages) can be priced directly, then no other information is needed in order to achieve cost effective abatement. In some circumstances, this is difficult to achieve because damages per unit of pollutant vary significantly, but it is a feasible goal for greenhouse gas emissions, so long as emissions can be measured or estimated.

Even when there are challenges in implementing the Pigouvian prescription due to measurement (e.g., pricing local air pollution differentially across space requires location-specific estimates of marginal damages), the subsidy approach still has an extra challenge compared to pricing strategies. It inherits the same inefficiencies that could follow from not knowing differences in marginal damages, and it layers on top of that uncertainty about substitution.

Harmonizing marginal costs across sectors is fudamentally more difficult in a subsidy-first

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[7] For a related analysis of how alternative policies compare in phasing out coal versus gas, see Borenstein and Kellogg (2023).

approach for the same reasons that it is difficult to get the relative subsidies right within a sector—both require information about substitution patterns to establish counterfactuals that cannot be directly observed. Viewed as a whole, the Inflation Reduction Act is attempting to reduce emissions across disparate sectors. If the goal were to achieve carbon emissions reductions in a cost effective manner across sectors, then the subsidies to transportation would need to be calibrated to have the same marginal abatement cost as the subsidies to the power sector, etc. This is possible only with a great deal of knowledge about substitution patterns for each of the sectors. As a result, in a subsidy-first approach, it is highly unlikely that the kind of cross-sectoral cost effectiveness that is often achievable in the Pigouvian approach is within reach of actual policies.

3.4 Market-size effects

In the model here, when the green goods create negative externalities, the Pigouvian approach would involve making all goods in the sector more expensive. This will generally cause the sector to a shrink, as the sector is too large relative to the rest of the economy (in the model, too little of the numeraire is consumed) when the externalities in the sector are unpriced.

For example, consider the car market, and interpret G_1 and G_2 as types of electric cars, with D_3 and D_4 representing internal combustion engine vehicles. The Pigouvian benchmark would apply a tax to all four vehicles, and we would expect the car market to shrink because all cars would be more expensive. In contrast, the green subsidy lowers the price of the (relatively) clean cars, and this will generally expand the car market. Even if lifecycle emissions of electric vehicles were driven all the way to zero, the green subsidy approach would still fail to shrink the internal combustion vehicle quantities as much as the tax benchmark.

This market size effect is fundamentally the same problem that Holland, Hughes, and Knittel (2009) document for environmental performance standards. That paper shows that a performance standard is equivalent to an emissions tax plus an output subsidy. The efficiency consequences of this mispricing can be a significant efficiency cost when the substitution elasticity for the sector (e.g., the overall elasticity of the car market) is large.

On the other hand, when we consider additional distortions in the economy, this market size effect can be a positive. Goulder, Hafstead, and Williams (2016), for example, demonstrate that for small changes in pollution, performance standards can be more efficient than pollution taxes because of interactions with factor supplies, if those factor supplies are already distorted by taxes on capital and labor. And, the market size effects could be helpful in counteracting mispricing of energy that comes from inefficient volumetric rates used to recover system fixed costs for electricity or natural gas, an issue which is discussed in Davis and Muehlegger (2010), Borenstein and Bushnell (2022), and Borenstein and Bushnell (2022).

3.5 Revenue implications for efficiency

The last consideration relates to the use of revenue to fund green subsidies. An obvious difference between a subsidy-first approach and the Pigouvian approach is the net revenue implications—the subsidy approach will expend revenue, whereas the Pigouvian approach will generate revenue. This has significant political consequences, and it likely has economic efficiency implications as well.

First, note that this is a substantial consideration in practice. On the one hand, taxing carbon could lead to substantial new revenue. Standard analysis of a modest carbon tax, starting as low as $15 per ton, is estimated to raise on the order of $100 billion per year in revenue (McKibbin, Morris, Wilcoxen, and Cai 2012), and taxes approaching the current social cost of carbon could raise much more. On the other hand, subsidies can sum to totals that are a meaningful share of the federal budget. The initial Congressional Budget Office (CBO) score of the IRA was $300 billion in tax expenditures over ten years. A number of estimates put the potential ten-year revenue impact of the subsidies at several times higher (e.g., Bistline, Mehrotra, and Wolfram 2023).[8]

Second, there is a traditional view that taxes have an efficiency advantage, but this depends on how revenue is actually raised or used in practice. Suppose we want to compare a tax and a subsidy that result in the same behavior responses and the same environmental outcome. By assumption, the cost of behavior changes are the same in both cases, but one case (the subsidy) expended revenue and the other raised revenue (the tax).

The taxes and subsidies are themselves transfers, but raising revenue to fund the subsidy requires an increase in some other distortionary taxes. This marginal cost of public funds, which is the welfare cost associated with raising revenue, represents the welfare cost of funding subsidies. Taxes, on the other hand, raise revenue and thus allow for the reduction of preexisting distortionary taxes, yielding a welfare benefit.

Thus, the traditional view of the marginal cost of public funds would suggest an efficiency advantage for taxes over subsidies (Goulder 2009).[9] This revenue cost will become a larger burden as a product or option becomes more diffuse and mainstream because a larger fraction of the total revenue will be going toward inframarginal actors, a point which is also made

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[8] The act was initially scored by the CBO as paying for these tax expenditures through changes in a corporate minimum tax, an excise tax on stock buybacks, the methane emissions tax and provisions to reduce spending on prescription drugs. This effectively illustrates the traditional point about the marginal cost of public funds—to hand out these subsidies, additional distortionary taxes have to be levied. In contrast, an emissions tax would have allowed reductions in capital or labor taxation.

[9] There is another layer of nuance in this analysis, which is known as the tax interaction effect. Raising taxes lowers real factor prices (the returns to labor and capital) which depresses factor supplies and thus creates distortions. Pollution taxes create a welfare cost through this tax interaction effect, whereas a subsidy creates a benefit. This weighs against the initial effects from the revenue changes, but Parry and Bento (2000) conclude that the net effect will generally imply that subsidies are less efficient than taxes.

in Boomhower and Davis (2014) and DeShazo, Sheldon, and Carson (2017). For subsidies targeting mature technologies like wind, solar and electric vehicles, the welfare costs associated with funding transfers can become a meaningful fraction of the total welfare effect of the policy because a large majority of the revenue is going to inframarginal recipients.

A subsequent literature has challenged some of the main conclusions about the marginal cost of public funds. That literature has sometimes argued that revenue implications can be ignored when setting environmental tax rates. One strain of that literature demonstrates that the marginal cost of public funds is equal to one in an optimized tax system because the benefits from redistribution offset efficiency cost (Jacobs and de Mooij 2015), and another strain argues for pairing environmental taxes with modifications of the existing tax system that offset benefits (Kaplow 2012).

In these contexts, the efficiency differences between subsidies and taxes related to revenue might be neutralized. In practice, however, the tax system may not be at an optimized point, and environmental policy may not be paired with a benefit-offsetting adjustment to the existing tax system. Then, the revenue implications will matter. At the same time, the possible efficiency benefits of raising revenue depend on what the government actually does in practice, which may be suboptimal (Babiker, Metcalf, and Reilly 2003).

In sum, as a theoretical matter, there is ambiguity about how to assess the welfare implications associated with a tax that raises revenue as opposed to a subsidy scheme that achieves the same environmental outcome but expends revenue because the details of implementation matter. As a practical matter, it is clear that large swings in public funds will have efficiency implications to the extent that they change the direction of future tax policy, which seems reasonable given the magnitudes involved.

4 Caveats: Things the model does not capture

The model presented in this paper was deliberately simple. Its aim was to highlight a set of specific efficiency problems centered on information requirements in a subsidy-first approach. I note here a partial list of additional considerations.

As mentioned in the introduction, the model assumes one relevant jurisdiction and complete coverage. In a situation with leakage across jurisdictions, green subsidies can play a different role Kotchen and Maggi (2024).

Green subsidies most often (though not always) subsidize an energy-consuming durable good. Policies targeting durable goods, like energy efficiency standards or product rebates, have a critical inefficiency in that they encourage switching towards a cleaner durable, but fail to create the right incentive on the utilization margin. Green subsidies that target durable goods will suffer from the same inefficiency, but the model (and the discussion) abstract from this consideration.

The model focuses on a particularly simple case where the modeled sector is separable from the numeraire and income is exogenous. A prior literature has considered how complementarities between leisure (labor supply) and externality-creating goods affects the optimal corrective tax (e.g., West and Williams 2007). My model abstracts from those considerations.

The model also abstracts from a similar set of concerns related to the substitution between the taxed goods and the outside good. This can be relevant if the outside good itself has some externality that is not priced. In that case, the substitution rates to the outside good will affect second-best optimal subsidies.

This point is also important to raise because in that case (assuming there is a negative externality associated with the outside good that is not corrected), the second-best *taxes* in a Pigouvian approach will include some substitution parameters, as well as marginal damages. The paper makes much of the idea that the Pigouvian approach only requires information about marginal damages, but this is literally true only when there are no other distortions beyond the ones being modeled. That said, I conjecture that the inefficiency from ignoring these interaction effects will be quite different between the two cases because the substitution effects are playing a primary role in rationalizing the subsidies in the subsidy-first approach. This is a promising area for future research.

A related point stems from uncertainty about marginal damages themselves. The paper advocates the Pigouvian approach because one needs only know marginal damages to set policy. If we are uncertain of damages, as we emphatically are when it comes to the social cost of carbon, even that becomes a great challenge. In this case, the standard insight that a Pigouvian approach (assuming that emissions can be measured) will still lead to cost effective abatement, even if the total level of abatement will be wrong, applies. The green subsidy calibrated to the wrong social cost of carbon will get the wrong overall level of abatement, but it will also misallocate abatement across margins because of relative mispricing. Nevertheless, if we are dramatically inaccurate about the social cost of carbon, the difference in efficiency between a subsidy-first approach that struggles to correctly differentiate among products may turn out to be a small part of the inefficiency of either policy compared to a first-best that sets the right social cost of carbon.

The model also does not provide resolution on possible learning spillovers. The optimal design of subsidies to encourage learning by doing will frequently involve more complex dynamic considerations (e.g., Langer and Lemoine 2022). Moreover, while direct pricing subsidies are a possible way to address such spillovers, the policy toolkit also includes options ranging from direct research and development support to intellectual property protection to advanced market commitments (Bloom, Van Reenen, and Williams 2019).

5 Implications for complementary policies

Until now, the paper has focused on comparing green subsidies in a subsidy first-approach against the Pigouvian approach when those policies are viewed in isolation. Another set of questions pertain to how green subsidies might interact with other policies. Here I briefly discuss whether our assessment of the efficiency of green subsidies is likely to change substantially when viewed in conjunction with other policies.

First, might green subsidies help fill in the gaps left by incomplete carbon pricing systems? The US does not have comprehensive emissions pricing at the national level, but there are cap and trade systems along the West Coast (California, Washington and a pending policy in Oregon), and eleven states in the Northeast are part of the Regional Greenhouse Gas Initiative (RGGI). Roughly a third of the US population is in a state with some carbon price.

The model can incorporate this if we interpret G_1 and D_3 as being a green and dirty activity in a jurisdiction with some pricing rules (e.g., California), whereas G_2 and D_4 are the corresponding activities in a jurisdiction without pricing (e.g., the Midwest), and we recognize that the substitution matrix will reflect very limited (or zero) substitution across borders. In this case, *differentiated* green subsidies could be a relatively effective way to address jurisdictional gaps. The subsidy to G_1 would be lower (it would go to zero in the limit if the externality were fully priced for both G_1 and D_3). If the only possibility was an undifferentiated (uniform across jurisdiction) subsidy, there still might be some role for a green subsidy, but it will end up balancing "overpricing" in some jurisdictions against "underpricing" in others.

Second, suppose instead that existing policies had complete coverage, but they were too weak for some reason. Could green subsidies be used to "top off" such a policy? For example, suppose that a jurisdiction had a carbon price, but it was below the social cost of carbon, perhaps because of political barriers. Does adding green subsidies improve efficiency?

The answer depends on the nature of the initial policy. Suppose first that there is a carbon *tax* in place, but it is too low.[10] This possibility is accommodated in the model if we interpret the ϕ terms as the *unpriced* portion of the externality (i.e., $\phi =$ damages per unit - tax per unit). In that case, the model applies directly, and a green subsidy scheme could be welfare improving, though it will be subject to the weaknesses pointed out above as compared to simply raising the tax.

Green subsidies will interact very differently, however, if the preexisting policy is a carbon

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[10] This is an apt description of carbon prices in the US. RGGI auction prices were consistently below $10 per ton for many years, and only broke past $20 per ton for the first time in the summer of 2024. (Historical auction prices are available at `https://www.rggi.org/auctions/auction-results/prices-volumes`.) California's cap and trade prices have been somewhat higher, though they were constrained by a binding price floor in most recent years, but have recently risen to as much as $40 per ton. (A discussion of recent auction prices is available at `https://www.eia.gov/todayinenergy/detail.php?id=62644`.) Current guidance from the EPA indicates a social cost of carbon that is at least three times recent high prices in California (Environmental Protection Agency 2023).

price achieved through a cap and trade program. In that case, if the policy has set an absolute cap on emissions that is binding both before and after the green subsidy scheme is introduced, then by construction the subsidies have no effect on emissions. Subsidies would shift incidence by injecting taxpayer funds into a sector, and they would alter the cost effectiveness of abatement. If the initial cap and trade program were set efficiently, then adding a green subsidy would tilt abatement towards the green goods (as opposed to changes in market size or adjustments between the dirty options) over and above that which would occur in an efficient benchmark.

Similar effects could occur with other performance standards or quantity-based policies. Consider the case of a preexisting performance standard like Corporate Average Fuel Economy (CAFE) standards. CAFE standards include EVs when calculating compliance, so if a subsidy increases their market share, it relaxes the CAFE constraint and allows automakers to increase the average emissions of the rest of their portfolio. As long as CAFE is binding, the only way that EV tax credits affect emissions is if they change the overall size of the car market.[11] Similarly, layering subsidies for renewable generation on top of a binding renewable portfolio standard will not change the renewable share (Goulder and Stavins 2011).

The question of how best to combine green subsidies with other policy instruments is an interesting area for future research. The case for a portfolio of some policy that creates relative pricing combined with green subsidies seems most relevant in cases where the green goods are excluded from the other policy. The efficacy of a green subsidy to complement incomplete or overly lax existing policies likely hinges on whether the green subsidies can be well differentiated and on how a subsidy would "stack" with the other policy instrument.

6 The Inflation Reduction Act: a feast of subsidies

Might the foregoing model and analysis help us understand climate policy in the US today? Many of the most important climate policies in the US have been green subsidies, and this is more true now with the passage of the IRA. The IRA represents the most significant federal climate legislation to date aimed at mitigating greenhouse gas emissions in the US. That legislation does many things, but the biggest ticket items are various forms of green subsidies.

Table 3 provides a partial list of these subsidies. Sections 45 and 48 extend and modify production tax credits (PTC) that pay renewable power generators a subsidy per unit of electricity generated and investment tax credits (ITC) that cover part of the up front cost of building a

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[11] In fact, alternative-fuel vehicles have often been given a compliance "bonus" under CAFE, which means it is possible that increasing their adoption causes overall emissions from cars to *rise* (Jenn, Azevedo, and Michalek 2019). As discussed in Anderson and Sallee (2016), there are a number of additional reasons why CAFE standards are inefficient, ranging from their failure to change mileage decisions to the use of attribute-basing (Ito and Sallee 2018) to unintended effects on capital turnover (Jacobsen and van Benthem 2015). This discussion abstracts from those issues. Green subsidies levied on a per-vehicle basis due little to address any of these, though there is perhaps some role for subsidies to counteract the capital turnover problem (Sallee 2024a).

Table 3: Selected green subsidies contained in the Inflation Reduction Act

Section	**Type of subsidy**
45	Production tax credit for renewable power
48	Investment tax credit for renewable power
45U	Credit for power from existing nuclear plants
30D	Credit for clean new vehicles
25E	Credit for clean used vehicles
45W	Credit for clean commercial vehicles
30C	Credit for alternative refueling stations
40B	Credit for sustainable aviation fuel
45V	Credit for clean hydrogen
45Q	Credit for carbon sequestration
45Q	Credit for direct capture and sequestration
45X	Credit for manufacturing clean energy inputs
25C	Credit for energy efficiency improvements
25D	Credit for clean energy durables
45L	Credit for new home efficiency
179D	Credit for commercial efficiency improvements

renewable generator, respectively. Along with energy efficiency standards, these credits have been a bulwark clean energy policy for decades (Metcalf 2007). The IRA extended those provisions, which were set to expire, modified them to include bonuses for domestic content and prevailing wage conditions, and enhanced the transferability of tax credits. Technically the IRA sunsets these existing provisions and replaces them with new "technology neutral" credits which creates a pathway for other power sources, including nuclear, geothermal and biogas to qualify these credits conditional on rulings that would determine conditions under which these power sources qualify as "zero emission." The IRA also adds a new subsidy for power generated at *existing* nuclear power facilities. This provision departs from the focus on bringing new generators online, but is designed to delay retirement of existing nuclear plants, which have seen a wave of closures.[12]

To address greenhouse gas emissions in transportation, the IRA extended the personal income tax credit for electric vehicles, though it also added a host of domestic content requirements and eligibility restrictions based on vehicle price and household income designed to make the policies less regressive.[13] The IRA also introduced a subsidy for the purchase of a *used*

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[12] For the PTC and ITC, the presumed focus of the policy is on bringing new power generation online, but see Aldy, Gerarden, and Sweeney (2023) for evidence that the PTC affects marginal production decisions. There is also a provision by which the PTC can be renewed after a retrofit. For a discussion of the state of nuclear power plants and the consequences of their closure, see Davis and Hausman (2016).

[13] See Borenstein and Davis (2016), Coyne and Globus-Harris (Forthcoming) and Borenstein and Davis (2024)

electric vehicle, which every EV could earn once, in an attempt to direct benefits towards lower and middle income households. Substantial tax credits are also available for zero emission commercial vehicles in provision 45W. To address both the chicken and the egg, the IRA also has subsidies for alternative refueling stations in 30C. Section 40B offers a per gallon subsidy for sustainable aviation fuel.

One of the most debated provisions is 45V, which offers a per kilogram subsidy for the production of hydrogen that is rated to require emissions below specified thresholds. The subsidies are large—on the order of magnitude of the commodity price today, which is produced from natural gas. The debate surrounds the complications of attributing carbon emissions to hydrogen production. The IRA also has generous provision for carbon sequestration in 45Q, which in some circumstances can be stacked with other credits.

Section 45X provides tax credits for manufacturing of specific clean energy inputs, which is part of the strategy to build complete supply chains for key technologies, including EV batteries that can only qualify for the EV tax credit if they meet domestic content requirements.

Section 25C extends energy efficiency improvements and rooftop solar costs for residential structures, and Section 179D has related provisions for commercial structures. Section 25D provides subsidies for heat pumps meant to spur electrification of space and water heating in homes. Section 45L has special credits for new home construction that meets certain efficiency requirements.

6.1 What might the model tell us about the IRA?

To the extent that these provisions can be rationalized by learning spillovers, then they may fit well into the Pigouvian approach. In that case, the optimal value of those subsidies would be calibrated against learning rates.

But, the IRA was formulated in a context where there is incomplete carbon pricing—pricing that covers only a portion of the economy and at rates that are arguably too low—and a patchwork of regulations. There are some provisions in the IRA that put a price on emissions, notably a tax on fugitive methane emissions, but the IRA itself is overwhelmingly composed of subsidies and was viewed by its architects as an alternative to the carbon pricing approach that failed to pass through Congress several times, most notably during the Obama administration in the form of the Waxman-Markey bill. Thus, it may be useful to evaluate some of these provisions through a subsidy-first lens.

Nearly all of the subsidies create potential inefficiences related to market size effects—everything ranging from carbon sequestration credits to the various subsidies for vehicles and equipment on average make energy consumption cheaper. And, obviously, all of the subsidies require revenue.

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for estimates of regressivity.

Looking across the provisions of the IRA the supreme challenge of designing policies that achieve cost effective abatement by harmonizing marginal cost of abatement is apparent. As far as I am aware, there was not even an attempt to calibrate the subsidies relative to each other so as to ensure cost effectiveness—that was not the goal. Rather, the IRA subsidies are essentially a checklist that ticks through each of the major decarbonization opportunities or technologies and slaps a subsidy onto each calibrated to make the green alternative viable within each sector.

In terms of the design of the subsidies, the subsidy-first approach would call for differentiated subsidies transportation, power, and building improvements, where the differentiation depends on emissions reductions relative to a counterfactual. The subsidies are systematically lacking in that sort of differentiation. Theory would suggest that many of these subsidies should be differentiated across products, across space, and over time in ways that are administratively difficult to achieve.

In terms of the failure to achieve relative pricing of dirty alternatives, this is a significant omission in the power, transportation, and home energy sectors. In all of those sectors, energy efficiency improvements and shifts among traditional fuel source products could be important. The subsidies in the IRA do not encourage those sorts of responses, leaving that work to other policies.

Do these subsidies interact with existing policies in a useful way? At the state level, there are carbon pricing policies in California and in a collection of states in the northeast. Many states also have some form of a renewable portfolio standard. Light-duty vehicles are subject to fuel-economy standards, and there are relatively new efficiency standards for commercial trucks. Appliances and equipment are subject to a slew of minimum efficiency standards administered by the Department of Energy. But, all of these policies take the form of a performance standard or emissions cap, so that, as discussed in section 5, the first-order effects of staking green subsidies on top of them is likely a reshuffling of burdens and a shift in abatement options rather than a change in total emissions.

The Clean Air Act and the Mercury and Air Toxic Standards, for example, impose significant costs on fossil fuel power plants through regulation of local air pollution that indirectly creates strong decarbonization incentives. Since the landmark ruling in Massachusetts versus the EPA, the Clean Air Act has also been determined to cover greenhouse gas emissions, but due to a series of administrative fits and starts and subsequent Supreme Court rulings, so far there has been little actual resolution of how the Clean Air Act will impact the power sector. Subsidies for nuclear and renewable power on top of those policies might be efficiency-improving, but further research would be necessary to analyze how well they fit together to approximate the incentives of a pollution price.

Does the subsidy-first view help us understand the IRA? It is certainly not true that the US is *only* pursuing decarbonization through subsidies. At the same time, it is clear that the main approach is not carbon pricing, and the IRA attempted to established a policy approach that leads with subsidies, albeit subsidies that rest on top of a nest of existing regulations. How to better combine green subsidies with other policies to achieve greater efficiency is key question for future research.

6.2 Examples from the IRA illustrate the information challenges that plague a subsidy-first approach

The model presented in this paper is directly relevant to thinking about the challenges of determining how to calibrate key subsidies in the IRA like the production and investment tax credits for renewables, the credit for production from existing nuclear power plants, subsidies for heat pumps, and credits for alternative fuel light-duty and commercial vehicles. The model emphasizes that a key difficulty comes from the fact that calibrating the subsidies requires taking a stand on counterfactuals.

For many provisions of the IRA, there are even more challenges related to the same difficulty—that green subsidies can only be quantified in light of information about counterfactuals, which is rarely available—that go beyond issues readily captured in the model. As such, the model perhaps helps point us towards a more general set of challenges for green subsidies.

To see this, I briefly discuss two final examples from the IRA. One example relates to the fact that the PCT and ICT for renewable power is set to be transformed into a technology neutral plan. This opens the door for nuclear power, geothermal or tidal power to qualify, but the law also allows for combustion technologies that are rated to have zero or negative life cycle emissions.

An example of a combustion technology rated to have negative emissions is methane captured from landfills or farms. When combusted, this gas creates carbon dioxide, but if the alternative is that this methane would have gone directly into the atmosphere, biogas could be said to have *negative* emissions. In contrast, if the methane would have been captured and used even in the absence of this particular policy—either because it qualifies for another subsidy, like the Low-Carbon Fuel Standard in California, or because it is regulated directly—then the emissions are positive. Thus, whether a given facility should qualify for the subsidy depends entirely on a counterfactual, which is, by construction, unobservable. This is the familiar additionality problem. In contrast, in a pricing approach, if the emissions from the landfill or farm are priced, then there is no need to assess counterfactuals. Given emissions prices, a biogas plant will emerge if that is the best use of the resource, given private and social costs.[14]

At the time of this writing, we are two years since the passage of the IRA, and the US Treasury is still working on guidance to determine when a biogas plant would qualify. And,

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[14] An additional concern with biogas plants is that plants that qualify could earn an upfront ICT and then later switch to conventional gas because the IRS has a limited ability to clawback the ICT (Sallee 2024b).

this is a small example among many dozens of determinations and rulings that are necessary because many provisions, at their root, require taking a stand on counterfactuals.

Relatively little debate has occurred around the biogas provision, but there has been a great deal of debate over other provisions, perhaps none more than the 45V credits for clean hydrogen. The hydrogen tax credit is technology neutral and offers a per kilogram subsidy depending on the lifecycle carbon emissions associated with the production of the gas. Conventional hydrogen is produced from natural gas through a process called steam methane reformation. One option for earning a 45V credit is to attached carbon sequestration to a conventional production process. This is generally called blue hydrogen. So-called green hydrogen instead uses electrolysis to separate hydrogen atoms from water. The electrolysis creates no emissions at that phase of the process, but the electricity needs to come from somewhere.

The main debate over 45V was how to determine the carbon emissions from the electricity used in green hydrogen production. To figure this out, the Treasury has to set rules that essentially establish a counterfactual. The problem is that any facility connected to a grid will be drawing grid emissions, so the thing we need to know is how the entire grid emissions would differ if that facility didn't exist. This is complicated to say the least, and Treasury needs to issue ex ante rules. But, the problem is even harder than that because even a facility that was entirely "islanded"—i.e., has its own wind and solar production not attached to the grid, but only feeding the electrolysis facility—would still possibly impact grid emissions if those same solar and wind facilities would have been built and connected to the grid if the hydrogen facility didn't exist.[15]

Again, the contrast with a pricing approach makes clear how much higher is the degree of difficulty in creating the desired incentives for subsidies. Under a pricing scheme, emissions from hydrogen production would be priced, and clean hydrogen would be produced if, accounting for those emissions as well as private costs, the green hydrogen was a viable way to reduce emissions in downstream applications compared to existing fuels.

7 Conclusion

This paper offers an analysis of green subsidies through a focus on a what I call the subsidy-first approach, which is summarized as the use of green subsidies *in lieu* of Pigouvian taxes.

The second-best subsidies in a subsidy-first approach depend on both marginal damages and a collection of substitution effects, and the second-best subsidy for each product depends on its unique substitution profile. The most fundamental point of the paper is that this implies that green subsidies will be less efficient than Pigouvian approaches, either because this information

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[15] Islanded systems are far less economical, so this is unlikely to be how most projects get built, but the fact that this leaves ambiguity illustrates the deep challenge of the problem, as argued in Sallee (2023).

is unavailable or because green subsidies will simply not be differentiated along the lines of substitution.

This is the first of five types of inefficiencies identified in the paper: the inability to differentiate subsidies, the failure to price dirty alternatives, inevitable cross-sectoral inefficiency, market size effects and revenue implications. The model developed in this paper is very simple, but it allows for these issues to be discussed with some precision, and it can readily be adapted to describe a number of alternatives policy structures and efficiency challenges. The hope is that this framework and the delineation of the potential inefficiencies outlined in this paper will prove useful for researchers and policymakers interested in evaluating and improving green subsidies.

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A Derivation of results

Result 1. *When* $t_1 = t_2 = t_X = \phi_X = 0$, *the second-best subsidies are equal to:*

$$s_1^* = \phi_1 - \phi_3 \left[\frac{\frac{\partial D_3/\partial s_2}{\partial G_2/\partial s_2} - \frac{\partial D_3/\partial s_1}{\partial G_2/\partial s_1}}{\frac{\partial G_1/\partial s_1}{\partial G_2/\partial s_1} - \frac{\partial G_1/\partial s_2}{\partial G_2/\partial s_2}} \right] - \phi_4 \left[\frac{\frac{\partial D_4/\partial s_2}{\partial G_2/\partial s_2} - \frac{\partial D_4/\partial s_1}{\partial G_2/\partial s_1}}{\frac{\partial G_1/\partial s_1}{\partial G_2/\partial s_1} - \frac{\partial G_1/\partial s_2}{\partial G_2/\partial s_2}} \right]$$

$$s_2^* = \phi_2 - \phi_3 \left[\frac{\frac{\partial D_3/\partial s_1}{\partial G_1/\partial s_1} - \frac{\partial D_3/\partial s_2}{\partial G_1/\partial s_2}}{\frac{\partial G_2/\partial s_2}{\partial G_1/\partial s_2} - \frac{\partial G_2/\partial s_1}{\partial G_1/\partial s_1}} \right] - \phi_4 \left[\frac{\frac{\partial D_4/\partial s_1}{\partial G_1/\partial s_1} - \frac{\partial D_4/\partial s_2}{\partial G_1/\partial s_2}}{\frac{\partial G_2/\partial s_2}{\partial G_1/\partial s_2} - \frac{\partial G_2/\partial s_1}{\partial G_1/\partial s_1}} \right].$$

Derivation: The consumer's maximization problem in 1 will yield the following first order conditions:

$$\frac{\partial U}{\partial G_1} = P_1 + s_1; \quad \frac{\partial U}{\partial G_2} = P_2 + s_2; \quad \frac{\partial U}{\partial D_3} = P_3; \quad \text{and} \quad \frac{\partial U}{\partial D_4} = D_4.$$

The planner's problem is to maximize 2 with respect to s_1 and s_2. The first-order conditions are:

$$\begin{aligned} \frac{\partial SWF}{\partial s_1} &= \left(\frac{\partial U}{\partial G_1} - P_1 - \phi_1 \right) \frac{\partial G_1}{\partial s_1} + \left(\frac{\partial U}{\partial G_2} - P_2 - \phi_2 \right) \frac{\partial G_2}{\partial s_1} \\ &+ \left(\frac{\partial U}{\partial D_3} - P_3 - \phi_3 \right) \frac{\partial D_3}{\partial s_1} + \left(\frac{\partial U}{\partial D_4} - P_4 - \phi_4 \right) \frac{\partial D_4}{\partial s_1} = 0. \\ \frac{\partial SWF}{\partial s_2} &= \left(\frac{\partial U}{\partial G_1} - P_1 - \phi_1 \right) \frac{\partial G_1}{\partial s_2} + \left(\frac{\partial U}{\partial G_2} - P_2 - \phi_2 \right) \frac{\partial G_2}{\partial s_2} \\ &+ \left(\frac{\partial U}{\partial D_3} - P_3 - \phi_3 \right) \frac{\partial D_3}{\partial s_2} + \left(\frac{\partial U}{\partial D_4} - P_4 - \phi_4 \right) \frac{\partial D_4}{\partial s_2} = 0. \end{aligned}$$

Substituting the first-order conditions from the consumer allows elimination of price and marginal utility terms:

$$\begin{aligned} 0 &= (s_1 - \phi_1) \frac{\partial G_1}{\partial s_1} + (s_2 - \phi_2) \frac{\partial G_2}{\partial s_1} - \phi_3 \frac{\partial D_3}{\partial s_1} + -\phi_4 \frac{\partial D_4}{\partial s_1}. \\ 0 &= (s_1 - \phi_1) \frac{\partial G_1}{\partial s_2} + (s_2 - \phi_2) \frac{\partial G_2}{\partial s_2} - \phi_3 \frac{\partial D_3}{\partial s_2} + -\phi_4 \frac{\partial D_4}{\partial s_2}. \end{aligned}$$

This is a system with two equations and two unknowns (s_1 and s_2). Rearranging yields the result.

Result 2. *When* $t_1 = t_2 = t_X = \phi_X = 0$, *the second-best uniform subsidy* ($s_u^* = s_1 = s_2$) *is* *equal to:*

$$
\begin{aligned}
s_u^* = \phi_1 \frac{\partial G_1/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u} &+ \phi_2 \frac{\partial G_2/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u} \\
- \phi_3 \frac{-\partial D_3/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u} &- \phi_4 \frac{-\partial D_4/\partial s_u}{\partial G_1/\partial s_u + \partial G_2/\partial s_u}.
\end{aligned}
$$

Derivation: This result follows by taking equation 2 and assuming $t_3 = t_4 = 0$ and that the planner has only one choice variable s_u, where $s_1 = s_2 = s_u$. The first-order condition is:

$$
\begin{aligned}
\frac{\partial SWF}{\partial s_u} = &\left(\frac{\partial U}{\partial G_1} - P_1 - \phi_1\right)\frac{\partial G_1}{\partial s_u} + \left(\frac{\partial U}{\partial G_2} - P_2 - \phi_2\right)\frac{\partial G_2}{\partial s_u} \\
&+ \left(\frac{\partial U}{\partial D_3} - P_3 - \phi_3\right)\frac{\partial D_3}{\partial s_u} + \left(\frac{\partial U}{\partial D_4} - P_4 - \phi_4\right)\frac{\partial D_4}{\partial s_u} = 0.
\end{aligned}
$$

The consumer's first-order conditions from maximizing 1 implies that marginal utilities equal tax inclusive prices for each good. Substituting those conditions into the above yields:

$$
0 = (s_u - \phi_1)\frac{\partial G_1}{\partial s_u} + (s_u - \phi_2)\frac{\partial G_2}{\partial s_u} - \phi_3 \frac{\partial D_3}{\partial s_u} - \phi_4 \frac{\partial D_4}{\partial s_u}.
$$

Rearranging yields the result.